Using Object-Oriented Modeling Techniques to Understand Urban Water Use Now and in the Future

A Test Application of the UML

Introduction

This paper describes an experimental effort to apply object-oriented modeling techniques, using the Unified Modeling Language (UML), to portray how the Department of Water Resources (DWR) currently measures and reports recent urban water use. This effort is meant to test the potential for applying object-oriented modeling techniques, and the UML notation, to discuss and develop the approach and tools needed to produce some of the quantitative deliverables desired for the next California Water Plan Update. As described in the California Water Plan Update 2005, the quantitative deliverables include:

- Water Portfolios
    - Describe where water originates, where it flows, and what it is used for based on recent data
- Future Scenarios
    - Describe expected changes by 2030 if water managers do not take additional action
- Alternative Response Packages
    - Describe packages of promising actions, predict expected outcomes, and compare performance under each scenario

In order to develop and present these quantitative deliverables in the next Water Plan Update, we must describe the water management system and how we think it functions and how it can be expected to change over the next 20-30 years. Creating this working description will require extensive interaction and collaboration between subject matter experts and other interested parties to develop an acceptable representation of what we "know".

Project Objectives

At the start of this project, DWR staff hoped to accomplish the following:

1. Have several staff members on the Water Plan team become familiar with object-oriented modeling (OOM) techniques and learn basic UML notation.
2. Apply the OOM techniques and basic UML notation to describe the current process for measuring and reporting urban water use.
3. Demonstrate how this approach can be useful to develop and agree on future analyses to produce the desired quantitative information in *Future Scenarios* and *Alternative Response Packages*.
4. Prepare documents that can be used to interact with interested subject matter experts and other stakeholders to determine if this approach might be useful to discuss other conceptual areas needed for future analyses.

The Need for More Clarity

As outlined in Water Plan Update 2005, the water plan team is attempting to conduct more comprehensive analyses and provide broader and more specific quantitative information than has ever been developed for California statewide water planning. A great deal of progress was achieved during the last water plan update cycle, and the current update cycle is building upon that success. In order to produce and report the desired quantitative information, the water plan team must get very specific about how they will produce the information. This is a challenge, because the analyses are complex, require multiple discipline expertise, and are highly interconnected. During the last update cycle, the previous methods used to articulate, document, and refine analytical approaches were not sufficiently robust to accommodate the desired increase in detail and comprehensiveness.

As a result, the DWR water plan team has been exploring other options for developing, communicating, testing and refining conceptual, theoretical, and numerical models. The hope is to find a technique or set of techniques that are sufficiently robust and well established that can be adopted to tackle the sizeable task of developing feasible and agreeable analytical methods to produce the desired quantitative deliverables.

Object-Oriented Modeling and UML

Object-oriented modeling techniques have been developed and used extensively by the computer software industry for over 20 years. Some advantages of using object-oriented analysis and modeling techniques include:

- They emphasize finding and describing the objects or concepts in the problem domain
- They use a familiar way of human thinking and abstraction
- They describe abstract system in terms of entities, interactions, and responsibilities
- There exists a widely used visual notation called the Unified Modeling Language[1]

Perspectives on the UML

According to Craig Larman (Larman 2005):

> The UML describes raw diagram types, such as class diagrams and sequence diagrams. It does not superimpose a modeling perspective on these. For example, the same UML class diagram notation can be used to draw pictures of concepts in the real world or software classes in Java.
>
> The same notation may be used for three perspectives and types of models:

[1] "The Unified Modeling Language is a visual language for specifying, constructing and documenting the artifacts of systems." Object Management Group, 2003. UML 2.0 Infrastructure Specification. www.omg.org.

1. **Conceptual perspective** – the diagrams are interpreted as describing things in a situation of the real world or domain of interest.

2. **Specification (software) perspective** – the diagrams (using the same notation as in the conceptual perspective) describe software abstractions or components with specifications and interfaces, but no commitment to a particular implementation (for example, not specifically a class in C# or Java).

3. **Implementation (software) perspective** – the diagrams describe software implementations in a particular technology (such as Java).

For this effort, we intend to apply the UML for the first two perspectives only.

Conceptual Modeling

Conceptual modeling is the process we use to put structure to a particular topic that allows us to discuss various elements of a complex process or interaction. We can form conceptual models of any experience such as how items move, the weather, life cycles, economic markets, etc. We all use conceptual models frequently in everyday life. Conceptual models include the words we use to describe something, the symbols we use to illustrate things, and the relationships we identify to be important.

A map is a simple example of a conceptual model. The map represents select information (much simpler than the real geographic space it models) in a standard way that allows people to share that information readily among diverse groups of people. The map is a conceptual model devised to fulfill one or more specific objectives. The primary objective is to aide people to navigate between different locations predictably and efficiently. The map is possible because of some important conceptual assumptions or constructs such as the use of scale and a two-dimensional system of reference.

Example of Object-Oriented Modeling[2]

Object-oriented modeling has been developed to help create analytical tools (in the form of computer software) to support some activity. Object-oriented modeling typically consists of two phases: analysis and design. During object-oriented analysis people emphasize finding and describing the objects – or concepts—in the field of the problem

[2] This description and example is taken from (Larman 2005).

under consideration. For example, if we were to model a flight information system, some of the concepts include *Plane*, *Flight*, and *Pilot*. During object-oriented design (or more simply, object design) people emphasize defining software objects and how they collaborate to fulfill the requirements of the software application. For example, a *Plane* software object may have a *tailNumber* attribute and a *getFlightHistory* method.

As described by within the software industry, the steps often used to arrive at an object design of a computer software based analytical tool include:

- **Define use cases**[3] – describe various ways of how the system under consideration will be used.
- **Define a domain model –** describe the important entities that play an significant role in the system being modeled.
- **Assign object responsibilities and draw interaction diagrams –** describe how software objects will model important events in the system being modeled. Often use UML sequence diagrams to illustrate the dynamic view of collaborating objects and their interactions.
- **Define design class diagrams –** define the static view of the class definitions and their relationships.

During this exercise, we applied elements of all four steps. These concepts are best illustrated by example. We illustrate these ideas in the sample application described below.

A Sample Application

We chose to apply these object-oriented modeling techniques to describe how we measure and report recent urban water use in California. Understanding how we currently measure and represent urban water use throughout California is an important piece to establishing a feasible and representative method for predicting future water demand in urban settings under different views of the future.

Quantifying Recent Urban Water Use

Many people that use the California Water Plan are interested in information about recent activity. They want answers to questions like "How much rain fell in a specific geographic area during the winter of 2005?", or "How much water did single family dwellings consume on average over the last year in a particular metropolitan area?" Of course these are useful and reasonable questions to ask and to answer. One might be

[3] Use cases are not an object-oriented artifact per say, but they are widely used to identify the objects and interactions important in modeling a system.

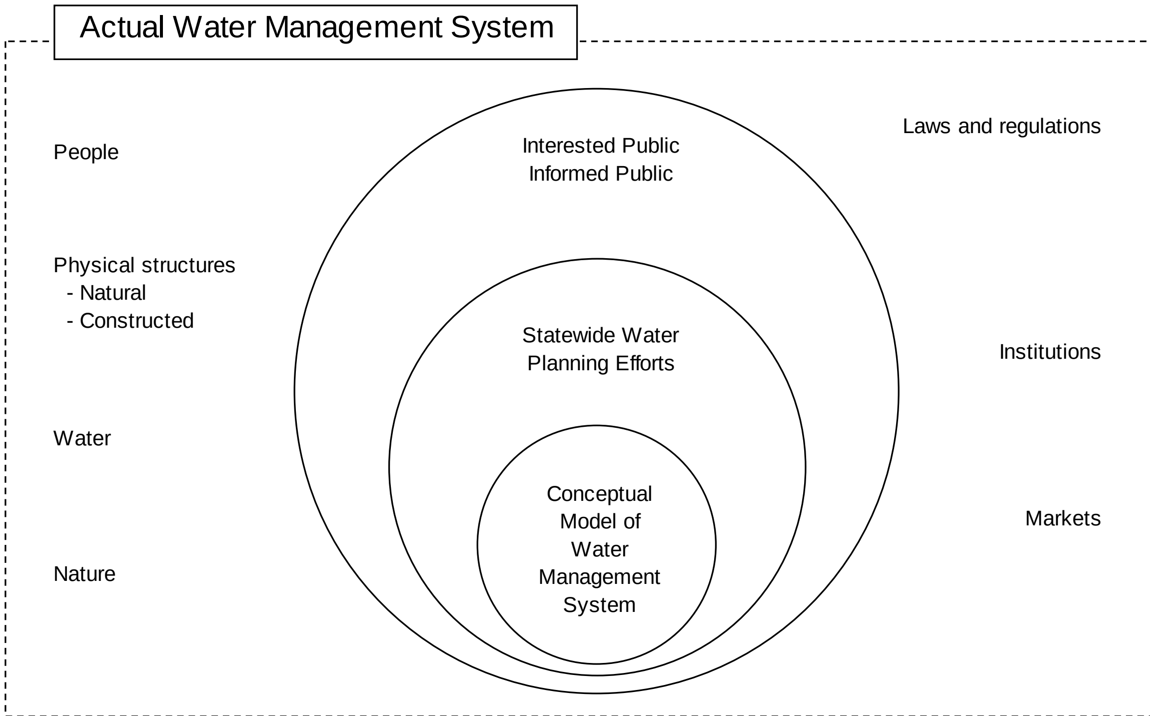


Figure 1 – Considering Various Perspectives for Conceptual Understanding and Analytical Tool Design

tempted to think that the answers should be easy to provide since the event has already occurred. However, while the event has already occurred, we do not have specific, relevant data for all components necessary to answer these types of questions directly. In every case, we have a sampling of data gathered by direct measurement means (such as physical measurement meters) or indirect measurement devices (such as questionnaires or voluntary reporting surveys).

As a result, DWR has developed an approach to gather strategic urban water use information at key locations and then parse and extrapolate that information to describe what has occurred at specific times over discrete geographic regions. This process of gathering selected information, synthesizing information from a variety of sources, and dividing and extrapolating this information is based on a number of conceptual assumptions. As is always the case when creating conceptual and numerical models of complex systems, there is a challenge to decide and communicate clearly, what perspective is being considered when creating the model.

Figure 1 shows how various perspectives of the "actual water management system" can be related. The actual water management system within California includes a large number of entities and is affected by countless relationships and outside influences, and is constantly changing. This immense complexity makes it impossible for us to fully observe and understand each and every factor and interaction that influences the behavior of the actual water management system. Nonetheless, we see that we have some influence over certain outcomes within the system (such as how much water is delivered to a city or irrigation district in a specified time period), and we want to make prudent decisions that create the most benefit for us now and in the future. Therefore, we create and use simplified representations (usually in the form of conceptual and numerical models) of the actual water management system to help us understand what the implications of our actions might be.

Interested public and informed public are two segments of people that are affected by the water management system and their views about the actual water management system are symbolized by the largest circle. The circle represents a particular perspective, or view, of what they consider to be important within the actual water management system and how the system functions when they plan for the future. Since the group forming the view is quite large, the groups' collective view is quite large and complex, with considerable variation among different members of this group.

As motivated by the interested public, and in response to the desire to better understand how the actual water management system can be operated to meet the desires of the interested public, DWR was charged by the California legislature to develop and provide relevant information about the water management system from a statewide perspective. The middle circle represents the perspective or view taken by DWR to provide the requested information. As illustrated within the diagram, if DWR is responsive to the original intent, their view will be included within the larger public view, and by necessity a little more specific to answer a set of specific questions.

Finally, in order to speak to what management actions, such as investments, changing regulations, etc. look promising for the future benefit of the public, DWR must craft a working conceptual model of how the actual water management system works with regard to the questions being addressed, how the actual system might evolve over time, and how it might respond to various actions the public can take. This view is represented by the smallest circle in Figure 1. Ideally, as shown in the diagram, the conceptual model of the water management system is fully contained within both the statewide water planning efforts view and the interested and informed public view. Obviously, other conceptual models of the "actual system" can exist.

This particular conceptual model under consideration (as represented by the smallest circle) needs to satisfy the objectives and concerns of both DWR and the interested and informed public. It will not represent all of the entities and interactions that occur within the actual water management system. For the purposes of statewide water management planning, the objectives and concerns that will be considered while developing this conceptual model have been identified and documented in the California Water Plan Update 2005.

Use Case 1 – Estimate Water Use in a Study Area

The first attempt to apply object-oriented modeling techniques and the UML was to describe how DWR currently estimates recent water use in a study area. Appendix A contains the text for *Use Case 1*, a class diagram for this use case (*Class Diagram 1*), and a sequence diagram (*Sequence Diagram 1*). The two diagrams illustrate a conceptual model of one process within the middle circle (Statewide Water Planning Efforts) of

Figure 1. (Appendix C describes how to read UML class diagrams and sequence diagrams.

The use case text describes the steps necessary to reach success according to how DWR currently estimates water use for a study area. The class diagram "describes the types of objects in the system and the various kinds of static relationships that exist among them. Class diagrams also show the properties and operations of a class and the constraints that apply to the way objects are connected" (Fowler 2004). The sequence diagram shows a number of objects and the messages that are passed between these objects in the use case.

This use case and the associated diagrams do not explicitly model the small circle in Figure 1 (Conceptual Model of Water Management System). Class Diagram 1 indicates that an object named "Urban Model" exists, and clearly the urban model must be based on a conceptual understanding of the water management system, but that conceptual model is not diagramed here.

If we want to illustrate more specifics about the Urban Model object, we can "zoom in" and describe a specific use case for the Urban Model and diagram the relevant objects and interactions, as follows.

Use Case 2 – Calculate Water Use by Customer Classes in a DAU

Appendix B contains a use case that describes how to calculate water use by customer classes in a DAU using the Urban Model shown in Use Case 1. Class Diagram 2 identifies the key objects and their static relationships. Sequence Diagram 2 shows the dynamic interactions between the objects.

More details for the *Business Rules* object in Class Diagram 2 are shown in Class Diagram 3 and Sequence Diagram 3.

What We Learned

As a result of this project, we learned that:

- Object-oriented techniques provide a useful way to create workable abstractions of statewide water resource planning processes. These processes can be abstracted and modeled at various scales or levels as described in Figure 1.
- Applying these techniques requires a sizeable initial investment of time and effort to develop a working knowledge of object-oriented modeling concepts and the UML.
- It was helpful to further our understanding and working knowledge of the OOM techniques and UML notation by attempting to model something that we have already done (the Urban Model).
- These conceptual modeling techniques show promise for creating specific, instructive documents that describe conceptual designs for future analyses.
- While robust and applicable, the UML can seem overwhelming if the user gets too focused on learning UML and forgetting the purpose of adopting it.

- A subset of the simple UML diagrams and notation seem adequate to describe useful conceptual models for statewide water resource planning analysis tools and techniques.

Next Steps

1. Share this information with DWR staff to determine how readily they can understand and use the notation to discuss the design and application of the Urban Model.

2. Use UML to diagram part of the conceptual model of the water management system that shows our understanding of the relevant entities and relationships necessary to link recent urban water use to future water demand.

3. Conduct a workshop with urban water use (and demand) experts and other interested stakeholders to describe this OOM and UML effort and discuss future applicability.

Bibliography

Fowler, Martin. 2004. *UML Distilled: A Brief Guide to the Standard Object Modeling Language, Third Edition.*

Larman, Craig. 2005. *Applying UML and Patterns: An Introduction to Object-Oriented Analysis and Design and Iterative Development, Third Edition.*

Appendix A – Estimate Water Use in a Study Area

Use Case 1

Estimate Water Use in a Study Area

Goal Level: Sea Level

Main Success Scenario:

1. Planner sends water use survey forms to public water systems and commercial and industrial water users.

2. Public water systems and commercial and industrial water users complete survey forms and send them to data entry

3. Data entry converts survey data to digital format

4. Data entry sends digital survey data to QA/QC.

5. QA/QC conducts quality control/quality assurance process

6. QA/QC sends digital data to Urban Water Use Model

7. Planner requests demographic data for study area from demographer

8. Demographer processes demographic data for study area

9, Demographer sends demographic data to Urban Water Use Model

10. Planner runs Urban Water Use Model

11. Planner reviews Urban Water Use Model output

12. Urban Water Use Model outputs is taken as estimate of urban water use in study area

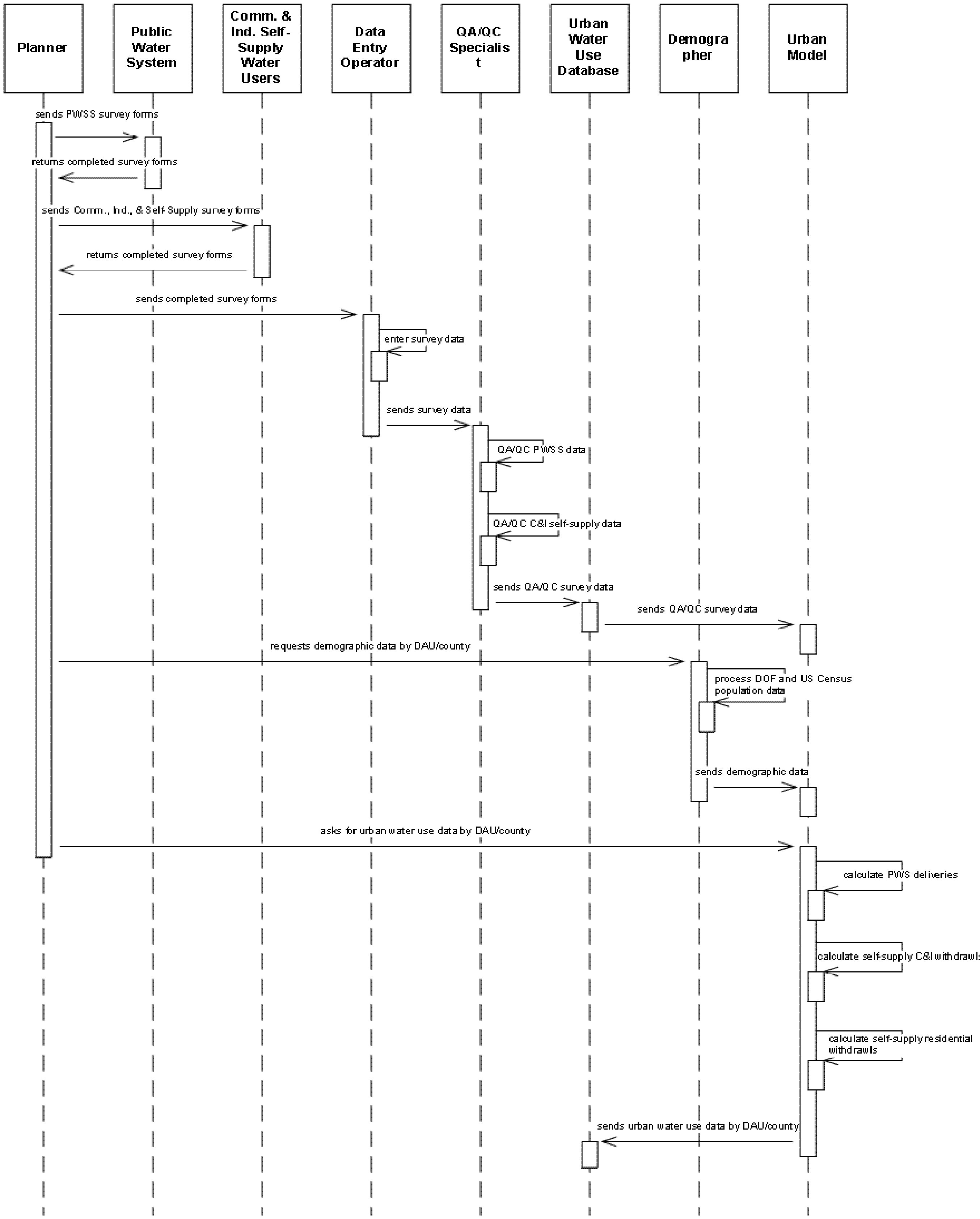
Extensions

10a: Urban Water Use Models fails to run

- .1 Planner checks for missing and invalid input data
- .2 Planner inputs missing data or corrects invalid data, returns to MSS at step 10

Class Diagram 1

Sequence Diagram 1



Appendix B – Calculate Water Use by Customer Classes in a DAU

Use Case 2

Use Case - Water Use by Customer Classes in a DAU
Goal Level: Sea Level

Main Success Scenario:

1. User starts the California Urban Water Use Model

    The User Interface displays the Main Interface;

2. User imports PWSS data of the year of interest

    Route: Main Interface \ Import.
    Choose a year from pull down list to match the year of the data. Click Import. A new window pops up which let the user navigate to the data folder. Input Class ensures the integrity of the imported data. Data Base Class creates a new table to host the newly imported data. Click Done to go back to the main interface.

3. User adds the population of the DAU-County of the year of interest

    Population data should be added to the table named "tblDAUCountyYears"

4. User QA/QC imported PWSS data

    Route: Main Interface \ Input... \ Public Water System (PWS) System.
    Choose a Year. Choose a PWS to inspect. The user can correct errors by directly typing in the correct info or number. The user can also choose to override the imported data by choosing one of two override check boxes, Override Production and Delivery Values or Override Delivery Values only

5. User enters DAU-Counties where PWS resides

    Route: Main Interface \ Input... \ Public Water System (PWS) System.
    Under tab General, click Add New to enter all the DAU-Counties where PWS resides and the PWS population residing in each of the DAU-Counties. The same info and values can also be entered using,
    Route: Main interface \ Input \ PWS Sub Groups.
    User identifies all PWSs within the DAU-County, and enter the same population value.

6. User enters Self Supply Users

    Route: Main interface \ Input \ Self Supply Users
    Choose a Year, DAU-County, and Self Supply User. Click on Add New to add Production and Delivery.

7. User chooses representative PWSs for residual self supply users

    Route: Main interface \ Input \ DAU County Data
    The default representative PWSs used to calculate residual self supply users are PWS subgroups within the boundary of the DAU-County. User can also select the check box of Override Representative Residual PWS data to type in new data to represent the residual self supply users.

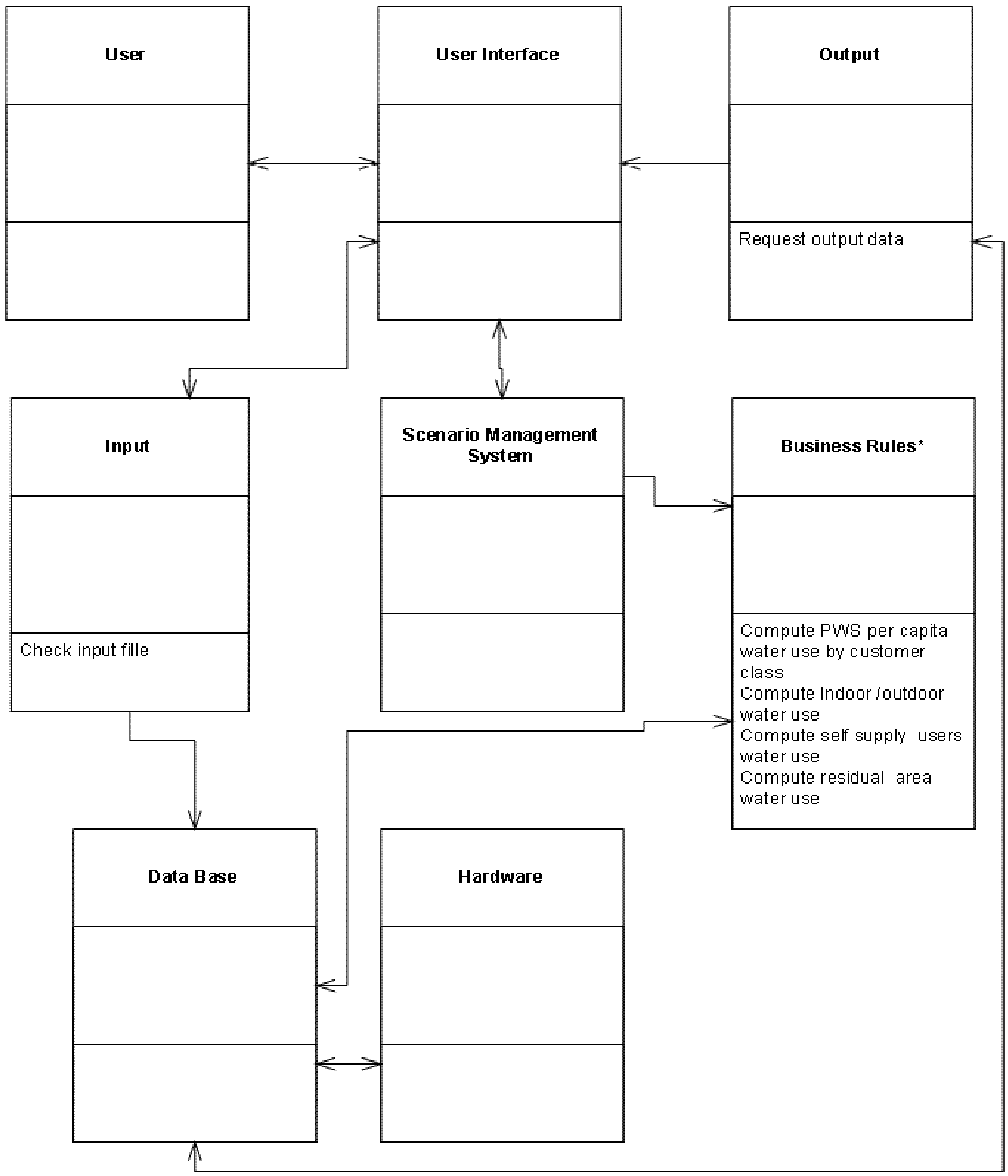
8. User requests to show final results

    Route: Main interface \ Reports... \ DAU-County Deliveries

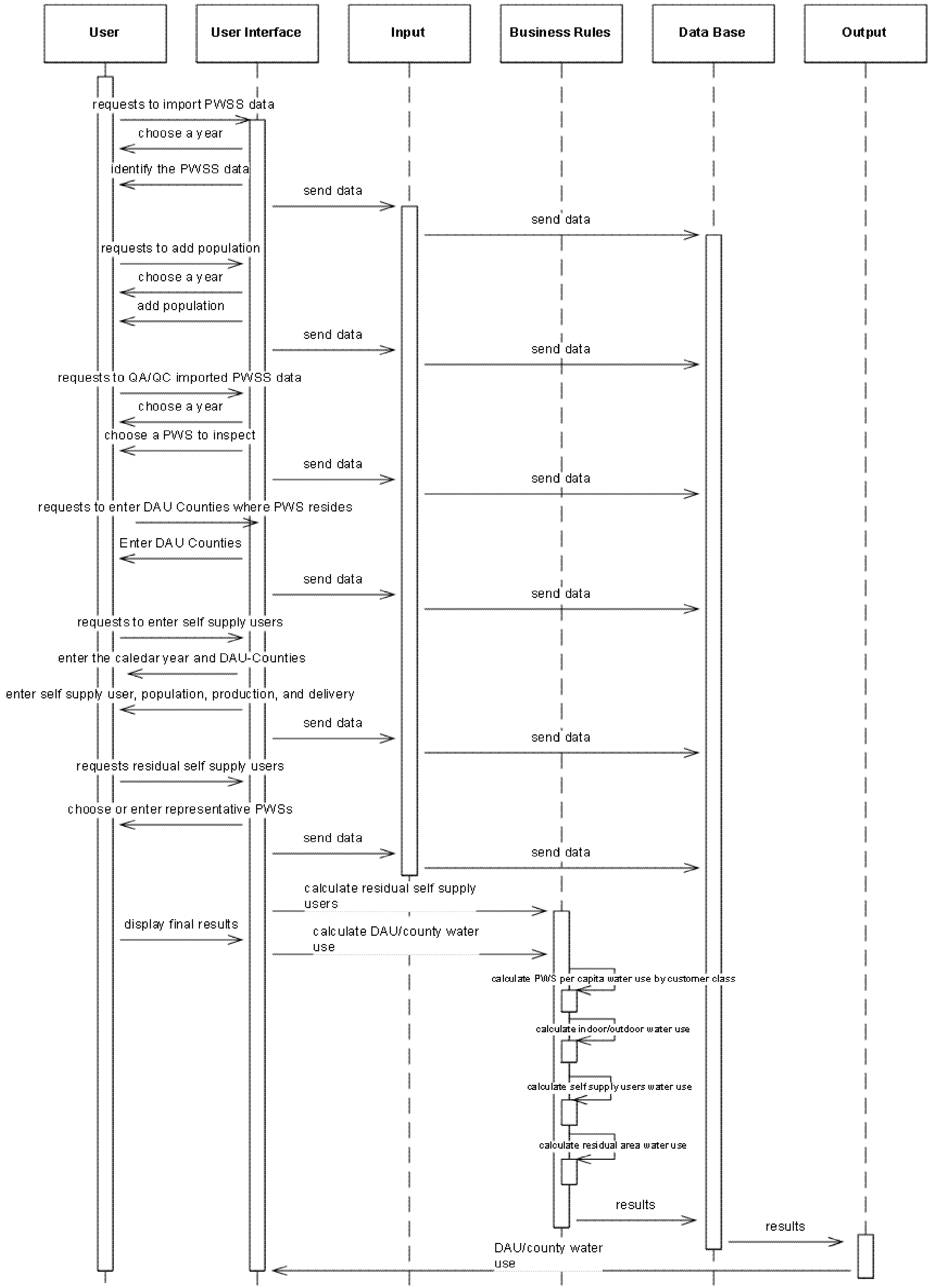
9. System provides the final results

    System shows monthly water deliveries of all customer classes for each DAU-County. User can query this table to narrow to the data needed.

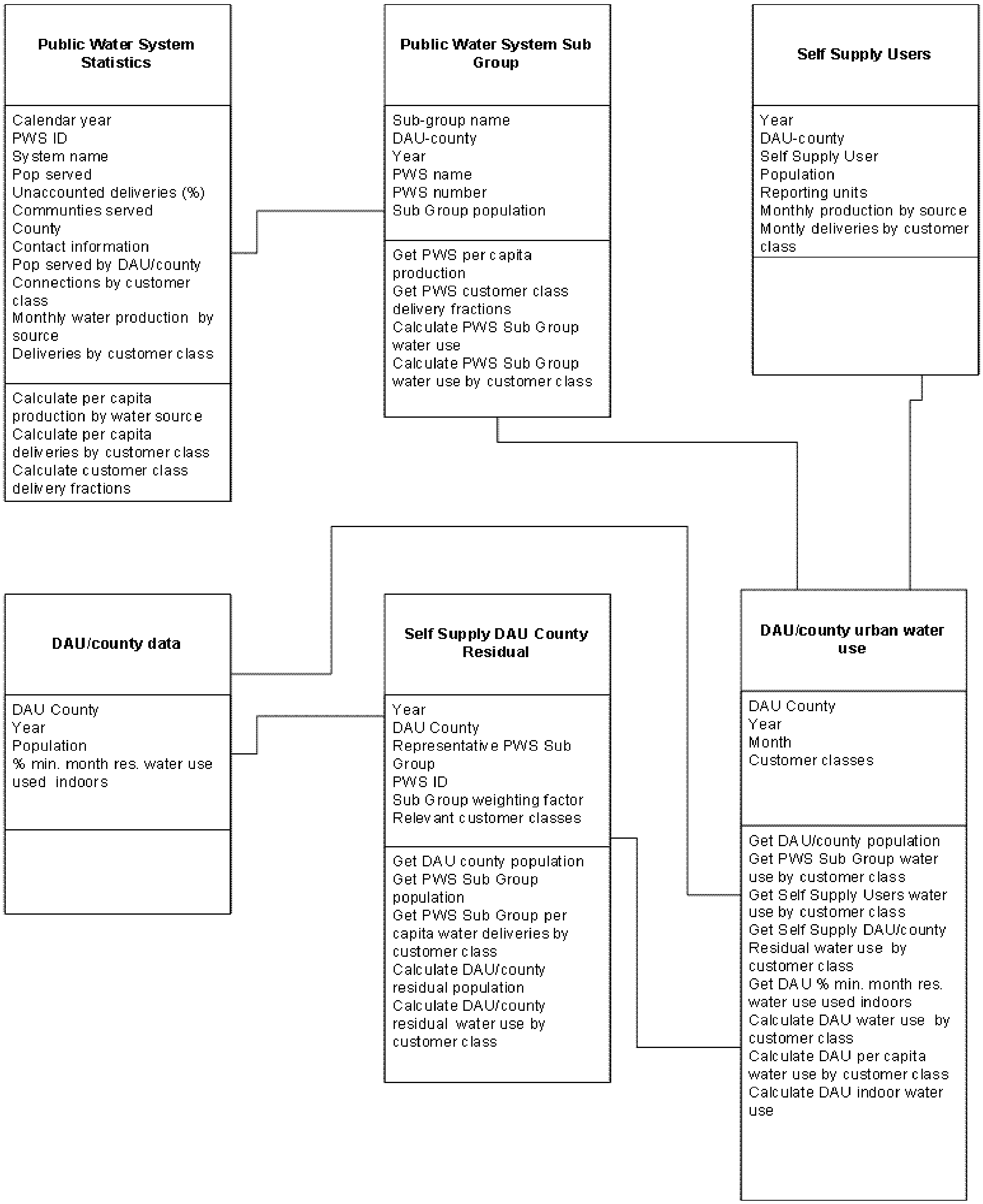
Class Diagram 2



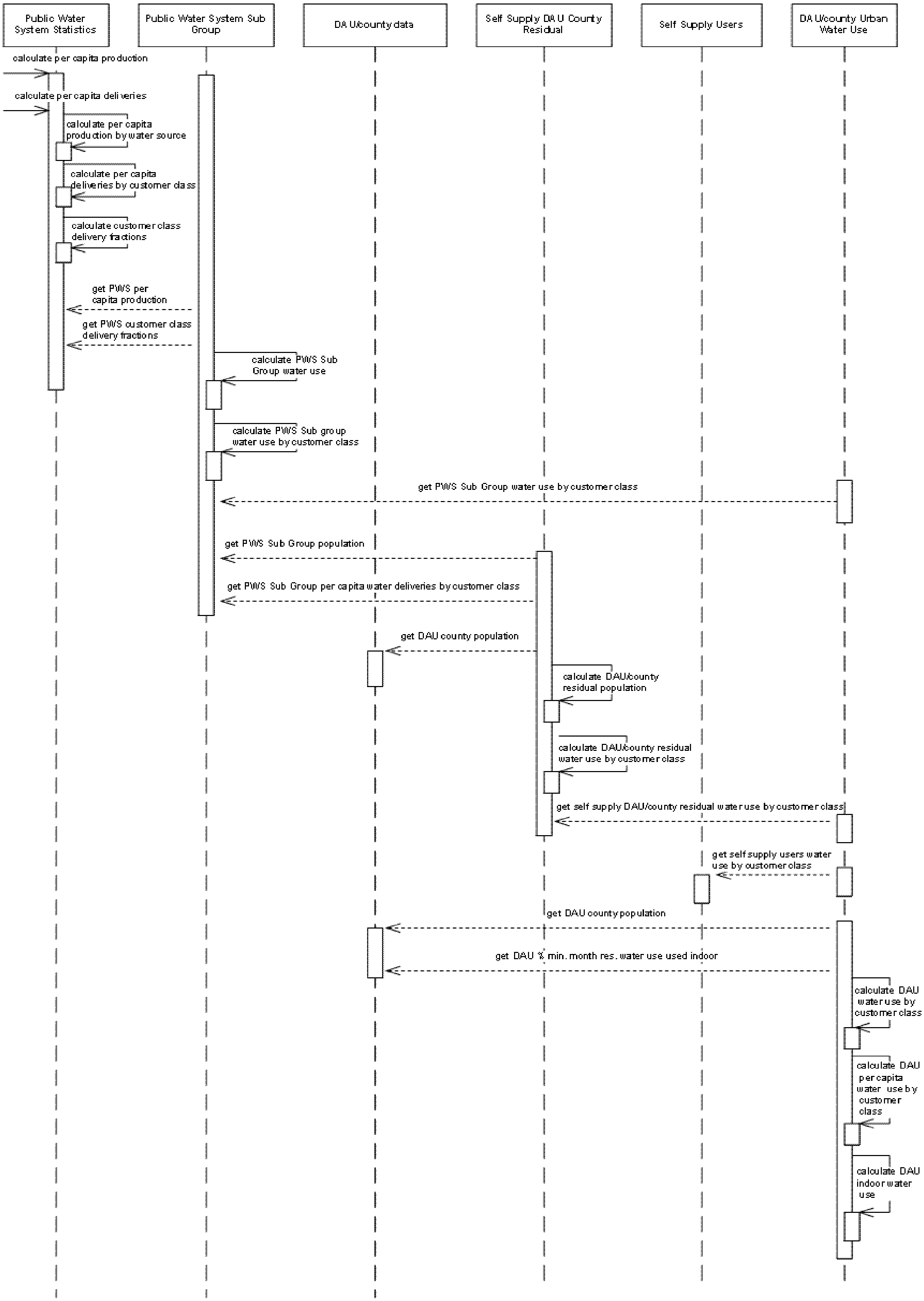
Sequence Diagram 2



Class Diagram 3



Sequence Diagram 3



Appendix C – How to Read Class Diagrams and Sequence Diagrams[1]

Class and sequence diagrams are two of the most often used diagrams in UML. They consist of simple graphical elements designed to show the most important aspects of some conceptual model of an actual system. These types of diagrams are each suited to illustrate different aspects of the same system. Class diagrams identify objects or participants within a system and illustrate fixed or static relationships. Sequence diagrams illustrate the dynamic interaction of those objects through a linear progression of time.

More specifically, a **class diagram** describes the types of objects in the system and various kinds of static relationships that exist among them (Fowler 2004). The most basic components in a class diagram are boxes and solid lines connecting the boxes. The boxes in the diagram are classes, which are divided into three compartments: the name of the class (in bold), its attributes, and its operations (Fowler 2004).

Public Water System Sub Group	← name of the class
Sub-group name DAU-county Year PWS name PWS number Sub Group population	← attributes of the class
Get PWS per capita production Get PWS customer class delivery fractions Calculate PWS Sub Group water use Calculate PWS Sub Group water use by customer class	← operations of the class

A meaningful ***name*** may convey a general idea of what the class is used for. The detailed ***properties*** of the class are conveyed by the ***attributes*** and ***associations*** of the class. The full ***features*** of the class are conveyed by ***properties*** and ***operations*** of the class. The ***attribute*** notation describes a property as a line of text (Fowler 2004). In some cases, only the name is specified.

In the context of using this notation to describe an analytical tool, an attribute can be thought of as a variable that can be used by the class that contains the attribute, or by other classes that have a relationship with that object. The value of the variable can be predetermined and stored, or can be generated. In the example,

Sub-group name DAU-county

Year PWS name
PWS number Sub Group population

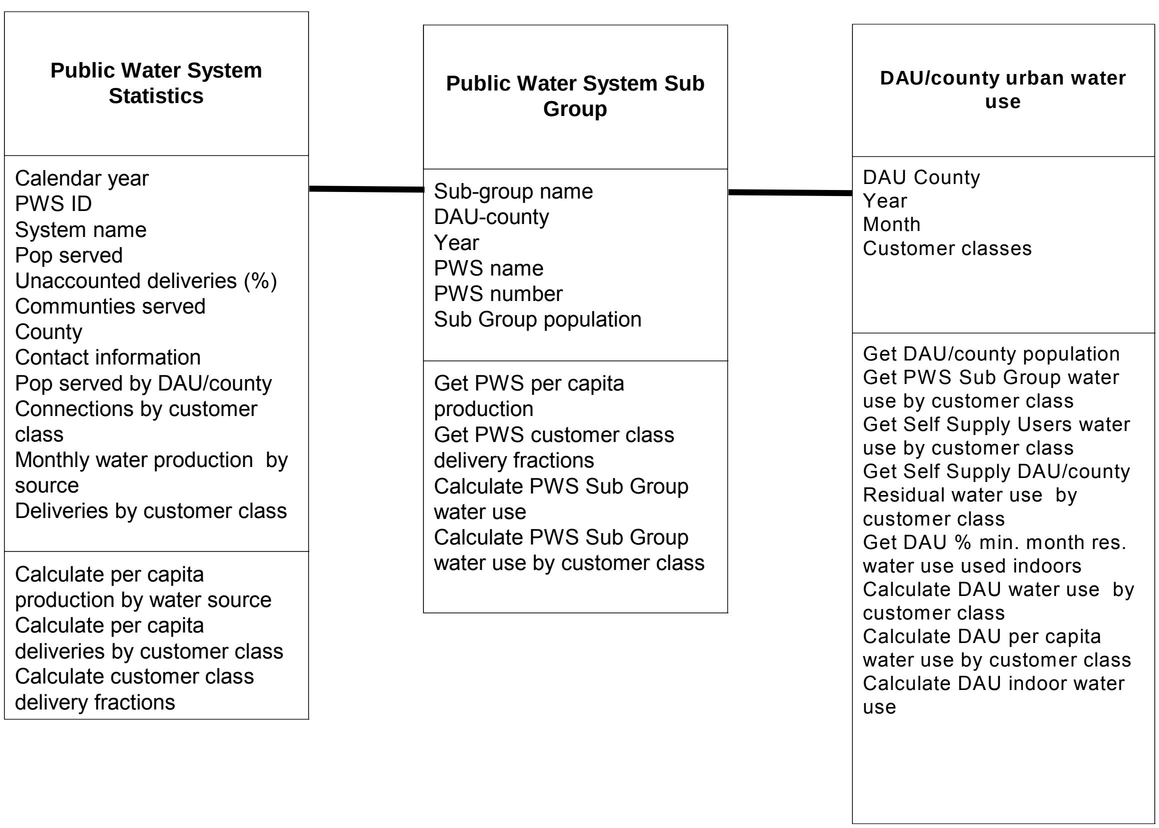
are known (or predetermined) variables, and are used to generate values for other variables.

Operations are the action that a class knows to carry out (Fowler 2004). In the example, class **Public Water System Sub Group** can carry out four actions,

Get PWS per capita production
Get PWS customer class delivery fractions
Calculate PWS Sub Group water use
Calculate PWS Sub Group water use by customer class

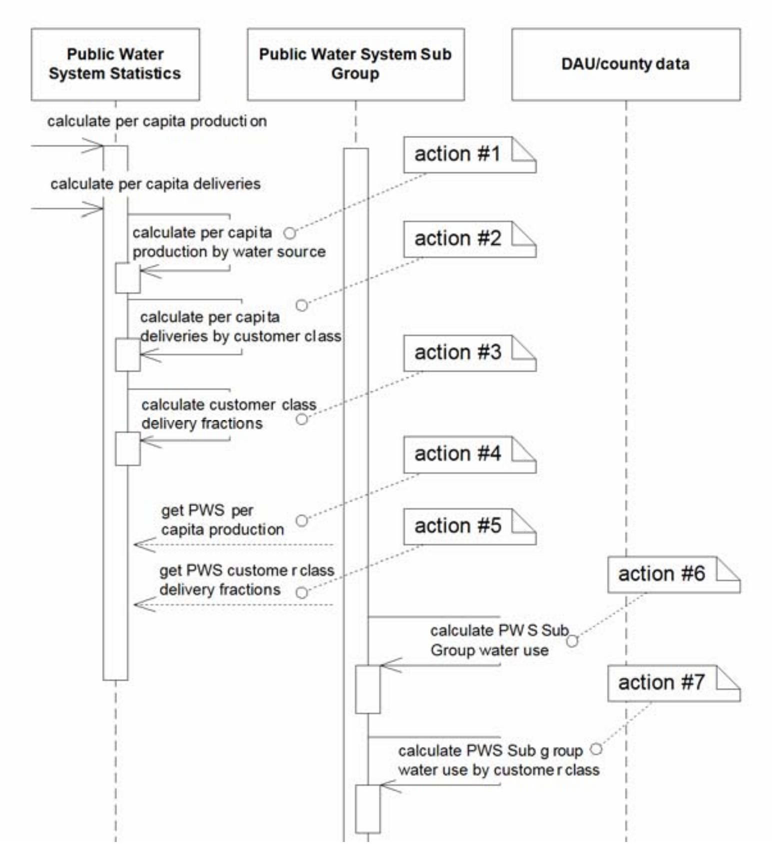
Two calculation actions are self-contained. Two “get” actions initiate interactions between classes, specifically, class **Public Water System Sub Group** initiates the processes of obtaining the values of PWS per capita productions and PWS customer class delivery fractions from another class, **Public Water System Statistics**.

Such relationship between the two classes is described by association. An **association** is a solid line between two classes (Fowler 2004).



As shown above, class **Public Water System Sub Group** is associated with both classes **Public Water System Statistics** and **DAU/county urban water use**. Interactions between classes are better described in a sequence diagram.

Sequence diagram is one of most common **interaction diagrams**, which describe how groups of objects collaborate in some behavior. In a sequence diagram, boxes representing participants (equivalent to objects here) are on the top of the page, and a lifeline runs vertically down the page from each box. The sequence of interactions occurs from top to the bottom. In the following example,



the sequence of actions occurs as following, (1, 2, & 3) per capita production by water source, per capita deliveries by customer class, and customer class delivery fractions are calculated first in self-call actions in **Public Water System Statistics**, (4 & 5) **Public Water System Sub Group** gets the calculated values of per capita production and customer class delivery fractions, and (6 & 7) PWS Sub Group water use and PWS Sub Group water use by customer class are calculated in self-call actions in **Public Water System Sub Group.**

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[1] The definitions and descriptions of class diagrams and sequence diagrams are adopted from Chapter 3 & 4, Fowler (2004), but only the portions that are relevant to this report.